Optimizing whole-body kinematics using OpenSim Moco to reduce peak non-sagittal plane knee loads and ACL injury risk during single leg jump landing

Dhruv Gupta[1], Cyril J. Donnelly[2,3] and Jeffrey A. Reinbolt[1]
[1]Mechanical, Aerospace and Biomedical Engineering, The University of Tennessee Knoxville, Knoxville, Tennessee, USA
[2]Rehabilitation Research Institute of Singapore, Nanyang Technological University, Singapore
[3]School of Human Sciences (Sport and Exercise Science), The University of Western Australia, Australia
Email: dgupta5@vols.utk.edu

Introduction

Every year over 200,000 anterior cruciate ligament (ACL) injuries occur in the US [1]. Out of these, approximately 60% are non-contact in nature, with >90% occurring during single leg landing or sidestepping [2]. Anterior tibial force in conjunction with non-sagittal plane (valgus, varus and internal rotation) knee moments during the weight acceptance phase has been shown to place the maximum strain on the ACL [3, 4]. We used OpenSim's forward dynamics residual reduction algorithm (RRA) to identify optimal whole-body kinematics that would reduce non-sagittal plane knee moments during side-stepping and single leg jump landing (SLJL) [5, 6]. This process involved two steps: 1) optimise model parameters (all actuators and tracking weights) to generate simulations with near zero residuals and 2) reduce non-sagittal plane knee moments and tracking weights to identify associated optimal kinematic patterns. Each of these steps used RRA and an outer level optimization routine [7, 8]. Although this technique is powerful, it is computationally expensive. Therein, it can take as long as 13 hours to run a single 70 ms simulation, with approximately 90% of the time spent on reducing residuals.

The use of direct collocation [9] is a known method capable of improving the speed of musculoskeletal simulations. OpenSim Moco [10] is a novel software package built to reduce the computational complexity of direct collocation technique. Both RRA and OpenSim Moco find control trajectories of a model's actuators over time, but they use different methodologies to solve for them. RRA finds controls at each time frame and numerically integrates model state derivatives to step forward in time, while direct collocation finds controls simultaneously with model states over an entire movement trajectory, which drastically reduces computational time. This approach also removes the need for model residuals to generate a stable simulation. The purpose of this study was to a) use OpenSim Moco to predict the optimal kinematics linked to reduced non-sagittal plane knee moments during SLJL and b) compare the optimal kinematics generated by OpenSim Moco to those generated using the RRA approach.

Methods

We used data from two participants performing SLJL. We started with the same generic actuators, tracking weights and scaled model. We applied similar constraints and costs to the OpenSim Moco approach as the second step of the RRA approach which were reducing the maximal torque capacity of the knee varus/valgus and int/ext rotation actuators, the sum of squared activation of the actuators and tracking weights of the joint coordinates. We then compared the optimal kinematic solutions and reductions in non-sagittal plane knee moments generated by the two approaches.

Results and Discussion

The mean difference in optimal kinematics generated by the two approaches was $0.8^{o}\pm0.35^{o}$ and $0.7^{o}\pm0.32^{o}$ for the two participants (P1 & P2). The reduction in peak resultant non-sagittal plane knee moments for each participant pre-to-post optimization were 75% (P1) & 45% (P2) for RRA, and 63% (P1) & 74% (P2) for the OpenSim Moco respectively. Both optimization methods resulted in similar kinematic strategies to reduce the peak non-sagittal plane knee moments, which was to re-positioning the knee towards the GRF vector, effectively reducing its moment arm (Figure 1). OpenSim Moco took 6 hours per optimization and RRA 13 hours.

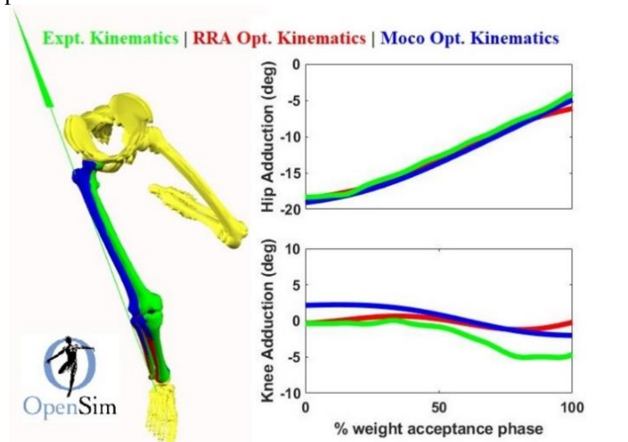

Figure 1: Comparison of Experimental, optimal RRA and optimal Moco kinematics (P2).

Table 1: Comparison of optimization approaches

Similarities	Over 40% reduction in peak non-sagittal plane knee moments
	Similar post-optimization kinematics
Differences	OpenSim Moco did not require residuals
	OpenSim Moco takes 50% less time

Significance

The use of OpenSim Moco reproduced the findings of an established forward dynamics approach (RRA) in one half the time. This improvement was accomplished as OpenSim Moco uses direct collocation, which is more computationally efficient than the previous approach. Our results for a high velocity movement like landing suggest that OpenSim Moco may perform even better for low velocity 'real world' applications within time constraints of clinical settings to treat movement disorders.

Acknowledgments

Experimental data was collected under NHMRC grant 400937.

References

1. DeMorat G. et al. Am J Sports Med, 2004; 2. Ekegren CL, et al. J Orthop Sports Phys Ther, 2009; 3. Markolf KL, et al. J Orthop Research, 1995; 4. Cerulli G, et al. Knee Surg, Sport Trauma, Anthro, 2003; 5. Donnelly CJ, et al. J Biomech, 2012; 6. Gupta D, et al. Am Soc Biomech, 2018; 7. Reinbolt JA, et al. Sim. Human Movement, 2011; 8. Weinhandl, et al. Clinical Biomech, 2013; 9.; Hairer E & Wanner G. Springer Series in Comp Math, 2010; 10. Dembia CL, et al. BioRxiv, 2019.